DUAL COMPUTER DISPLAYS REDUCE EXTRANEOUS COGNITIVE LOAD

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ROBERT ALLEN MILLER

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by

ROBERT ALLEN MILLER

APPROVED:

Dr. Cheryl Stenmark

Dr. Kraig Schell

Dr. Kyle van Ittersum

Dr. J. Will Dickison

04/03/2019

APPROVED:

Dr. Donald R. Topliff
Provost, VPAA, and Interim Dean, College of Graduate Studies and Research

ABSTRACT

Dual display desktop computers are becoming more prevalent in the home, workplace, and schools, yet there has been little research into how learning and productivity are impacted by having a second display. One useful method in exploring this question is to measure cognitive load during an intensive learning event. This study compared perceived cognitive load among participants in a military training program using one or two computer displays. Participants using dual monitors reported lower unnecessary cognitive load than participants using one monitor. The implications of these findings for theory and practice are discussed.

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The use of computers in business and education is becoming increasingly prevalent. With the rise of the use of technology, equipment costs and worker or student productivity are salient concerns for any company in the training of new employees. Technology is becoming increasingly fundamental in organizations because many jobs have evolved into information-based work processes that involve searching and sorting through massive volumes of data.

For businesses or schools that wish to provide computer stations for training and educational programs, one issue that these agencies must consider is whether to provide a single computer display or two displays to employees and students. The design of classrooms and work centers must consider the costs and benefits of each option, yet there is currently no empirical evidence as to whether a second display on a desktop actually improves learning or productivity.

The goal of the current study is to explore the effects of using dual display versus single display personal computers when students are exposed to a complex research problem with a single comprehensive standardized product as the expected outcome in a job training classroom environment. The type of task used in the current study is similar to a college student drafting a thesis using multiple academic articles as sources. Cognitive Load Theory can inform the study of the effects of adding a second display.

Publication Manual of the APA

Literature Review

Most research examining single versus dual displays has focused on single versus dual display presentation by instructors. Only one study examined the subject of dual displays on personal workstations. This qualitative study surveyed 17 academic library employees after switching from one display to two on their personal workstations and found that employees felt more productive and that the second display reduced interruptions in their "train-of-thought" (Russell & Wong, 2005). Another study within the Human Factors field found that participants planned a trip in less time when using two displays when compared to those who used a single display (Kang & Stasko, 2008). Thus, there is some evidence that using two displays may improve work outcomes. However, and perhaps due to the prohibitive costs of providing personal computers at each desk in universities, there is a dearth of empirical research on how learning is affected by the use of dual displays by *students and employees*.

Two studies of note have examined the relationship between cognitive load and the number of displays used by the instructor during classroom instruction. Lanir, Booth, and Wolfman (2013) conducted a qualitative study with 1,157 participants and found that beneficial practices enabled by using multiple displays included:

> …the ability to keep information persistent for extended periods, the increased flexibility in where and when information is shown, capability for side-by-side comparison of full screens of information, simultaneous visibility of both overview (‘‘roadmap’’) and detailed (‘‘content’’) information, and extra space to annotate information (p. 335).

Another study empirically supported the efficacy of multiple displays in student learning by using non-equivalent pre- and post-tests as well as a subjective approach involving 120 college students in a business course. The study measured overall cognitive load and the results showed a statistically significant reduction in cognitive load for learners whose instructors presented material on dual projection displays (Cheng, Lu, & Yang, 2015). Hsu, Chang, and Yu (2012) also conducted a study that found that when multiple displays were used by instructors, students reported significantly increased clarity and demonstrated improved learning.

Theoretical Basis

Cognitive Load Theory (CLT) has had a significant influence on instructional design over the last 30 years (Gerjets, Scheiter, & Cierniak, 2009). CLT focuses on identifying factors that inhibit learning by drawing cognitive power away from the learning process. A key premise of this theory is that there is a limited amount of working memory in the human brain and potentially unlimited long-term memory (Miller, 1956; Sweller, Van Merriënboer, & Paas, 1998). New information must first be processed in working memory before it can be transferred into long-term memory during a learning event (See Figure 1). This processing, according to Schema Theory, is linking the new information to previously known information in a construct known as schema (Orru & Longo, 2019).

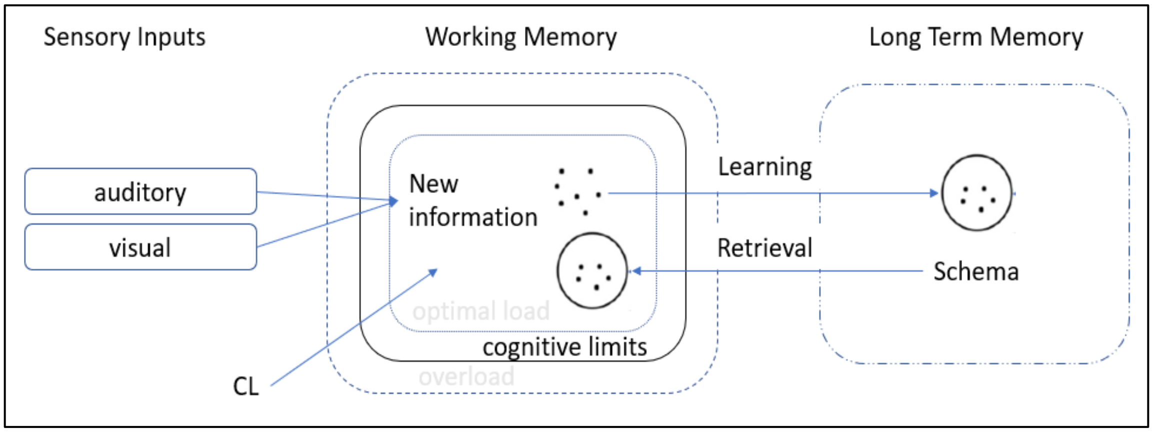

Figure *1*. The Process of Learning.

Learning induces three different types of cognitive load during the learning process. These types are *intrinsic cognitive load* (ICL), *extraneous cognitive load* (ECL), and *germane cognitive load* (GCL) (Gerjets, Scheiter, & Cierniak, 2009; Sweller, Van Merriënboer, & Paas, 1998). They are considered additive in the sense that if the sum of these cognitive load (CL) types does not exceed the CL capacity of the learner, then learning is facilitated. However, if the sum of the types of CL exceeds the CL capacity of the learner, then learning is inhibited.

According to CLT, ICL is the load inherent to the difficulty of the material being taught; it is influenced by the expertise of the learner and cannot be affected by pedagogical techniques (Cierniak, Scheiter, & Geriets, 2009; Gerjets, Scheiter, & Cierniak, 2009). ICL is best characterized by the amount and interactivity of information that must be held in the working memory for schema construction (Orru & Longo, 2019). In contrast, ECL "cause(s) learners to consume additional cognitive resources on unrelated information processing during the learning activity" (Cheng, Lu, & Yang, 2015, p. 129). For example, searching through source documents to find specific information can cause the learner to use additional cognitive load that is not related to the learning event. ECL is the component of CL that would be expected to be affected by changes in the learning environment such as using two display monitors. GCL is the mental effort necessary for constructing the schema during learning. GCL is increased when instructional design creates CL that benefits the transfer of information from the working memory into long term memory (Sweller, Van Merriënboer, & Paas, 1998). Gamification, abstraction, and elaboration are examples of instructional interventions that can increase GCL.

According to CLT, overall cognitive load during the learning event is equal to the sum of ICL, GCL, and ECL. If the overall CL does not exceed the learner's cognitive capacity, then learning is enabled. However, if the learner's cognitive capacity is exceeded, then "errors are more frequent, longer task execution times occur, sometimes even leading to the inability to perform an underlying task" (Orru & Longo, 2019, p. 27). Instructional processes and curriculum design, according to CLT, should focus on reducing ECL and maximizing GCL without exceeding the learner's cognitive capacity (Sweller, Van Merriënboer, & Paas, 1998).

In complex tasks, learners are faced with searching for and sorting through large amounts of data that far exceed the working memory of the average brain (Miller, 1956, p. 95). This phenomenon is compounded when learners must draw data from multiple sources (e.g., websites, documents, databases). On a single display personal computer, switching between various visual sources in the process of compiling data for analysis can potentially increase ECL and hinder the learning process. Subsequently, a second monitor should reduce the amount of switching, potentially reducing the amount of ECL and therefore the overall CL.

Until recently, only overall CL has been measured, and there was no known method for measuring the three types of CL individually in a generalized setting. Klepsch, Schmitz, and Seufert (2017) developed two instruments for measuring each type of load individually. They conducted two studies examining these instruments. In the first study, 95 participants were asked to complete the instrument after completion of several tasks that were designed to produce the three types of CL. Prior to completing the task, participants were taught about CLT in an attempt to determine if CL could be self-managed when participants were aware of it. The results were compared to a control group.

In the second study, 97 participants that had not been previously educated about CLT completed a second instrument. The authors designated this second study the *naïve* study. The results of the study found that the instruments they had developed were valid predictors of each type of load. The instrument developed for participants who had been trained on CLT demonstrated a slightly more valid measurement of CL, however, the authors designed and validated the second instrument for the more common situation wherein the participants would not have been trained in CL (Klepsch, Schmitz, & Seufert, 2017). This second instrument was used in the current study due to logistical issues that precluded training CLT to the participants.

Purpose of the Present Study

In order to expand on previous research examining the role of multiple information displays on cognitive load, the hypothesis of the current study is that the use of dual displays on personal computers will impact the CL of learners relative to a single display and improve learning when students are exposed to research-intensive job skills training. Specifically, the study examined whether having a second display affected task performance and perceived ECL. These concepts were examined using self-report surveys and industry standard performance measurement devices.

Significance of the Study for Theory

Findings from the current study will advance the understanding of cognitive learning processes. As previously mentioned, until recently, CL was measured holistically as there were no instruments that demonstrated validity and were able to measure each type of CL in a generalized setting. A review of the literature reveals that the results of most studies in the field were reported in general terms of increased or reduced overall load. Klepsch, Schmitz, and Seufert (2017) designed two new instruments that purport to be able to measure ICL, GCL, and ECL individually in a general setting. Over two studies in their initial article, the instruments were found to demonstrate validity with naïve and experienced samples, however further study is required to determine the instruments' usefulness in alternative settings. Reliability for the two instruments was reported by Klepsch et al. (2017) to be between α = 0.80 and α= 0.86 for all subscales.

The current study used a previously accepted instrument (Paas, Tuoyinen, Tabbers, & Van Gerven, 2003) that measures overall load in conjunction with the instrument that Klepsch, et. al (2017) recently developed for their "*naïve"* study measuring the three types of CL. Both instruments were used in an effort to provide further validation for the new instrument. Additionally, one aim of the present study was to compare perceived CL to actual task performance and provide more insight into the relationship between what students perceive and what they demonstrate.

Significance of the Study for Practice

The findings of the current study can also inform the areas of work center design and instructional design. The findings can provide business and school leaders with the empirical evidence necessary to analyze the costs and benefits of adding a second display to employee and student workstations. Additionally, instructional designers can benefit from an understanding of how information presented on dual displays affects the learning process and design future curriculum appropriately to reduce ECL and maximize GCL.

METHOD

Participants

Participants in this study were students in a military job skills training course. Participants ranged from 18 to 54 years of age (M = 22.24, SD = 6.09). Participants were randomly assigned for each class from a pool of incoming basic military training graduates by the school administration. Classes were then selected for recruitment by virtue of having the pre-requisite single or dual computer displays in their classrooms. The randomization of selection into the classrooms was sufficient to meet APA ethical standards. Of the participants approached about the study, 84 of 89 volunteered to participate. Participants were offered no incentives to participate and were assured that participation was voluntary and confidential.

The participant pool comprised of 52 males and 31 females with 26 males in each condition, 14 females in the single display treatment, and 17 females in the dual display treatment. Four participants reported a first language other than English. Sixty-two participants reported that their highest education completed was high school, four had completed an associate's degree, 12 had completed a bachelor's degree, and five had completed a master's degree. Participants averaged 2 years of military work experience and 4 years of non-military work experience. The majority of the sample was in the first three years of military service (86.9%).

Procedure

In this field study, participants were monitored as they completed a 128-hour research intensive job skills training module within an initial military job skills training course. The participants were taught about military weapon systems via lecture and tasked with researching and building three presentations that are identical to products that would be developed in the field; thus, the task involved a high-fidelity job simulation. The participants' tasks involved searching multiple sources (e.g. databases, intranet websites, PDF documents, etc.) and finding accurate technical specifications on specific complex weapon systems for detailed presentation to battlefield commanders. Participants also completed a 50-question written test on the lectured material.

Participants performed this training on a Microsoft Windows® based personal computer at each desk with a single display (n = 41) or two displays (n = 43). No other factors differed. The computers were on a closed network with no access to email or chat applications. Participant computer application access was restricted only to those pertinent to the task (e.g. Microsoft PowerPoint®, Word®, etc.). All material used was text or image-based and no audio aspects were introduced during the task. The participants were exposed to the same industry standard training and were graded on the same rubric by qualified military instructors. All study-related surveys and questionnaires were administered at the completion of the block of instruction. Participants were not informed about the study or asked to volunteer for the study until the end of the course of instruction. This procedure was intended to minimize the impact of the study on normal operations. All participants were briefed on the study and signed informed consent forms if they elected to participate. All participants were given an opportunity before and after the surveys were administered to withdraw from the study. The procedures for this between-persons study were approved by the Angelo State University Institutional Review Board.

Instruments

The dependent variables included three industry standard grading rubrics for the performance tasks and one industry standard written test. Participants also completed two surveys designed to measure CL. The first survey (overall survey) was adapted from several studies using an accepted method for measuring perceived cognitive load and included eight questions (Adapted from Cerpa, Chandler, & Sweller, 1996; Cheng, Lu, & Yang, 2015; Kalyuga, Chandler, & Sweller, 2000; Paas, 1992) For this survey, participants were asked to rate, on a seven-point Likert scale, various aspects of the difficulty and clarity of the course and how much effort they put into the course, with high difficulty and high clarity being high on the scale and low difficulty and low clarity being low on the scale ($\alpha = .79$). An example item was, "Rate the clarity of the material in the course." The scores of the Chen, et. al. survey were averaged per participant to define the overall perceived CL dependent variable.

On the second survey (combined survey), participants were asked nine questions rating, on a ten-point Likert scale, the more focused questions developed by Klepsch, et. al. (2017) designed to measure each type of cognitive load (overall $\alpha = .64$). The Klepsch, et. al. survey was added to provide further data to further assess evidence of its validity and to attempt to identify which aspects of CL would be affected by the addition of the second display. An example item was, "During this task, it was difficult to recognize and link the crucial information." Participants rated "Strongly Disagree" as low and "Strongly Agree" as high. Two questions focused on ICL ($\alpha = .71$), three questions on GCL ($\alpha = .71$), and four questions on ECL ($\alpha = .69$). This resulted in five dependent variables, ICL, GCL, ECL, and overall score for each survey. The overall survey and the combined survey were significantly correlated, $r = .63$, $p < .001$. Finally, a questionnaire with demographic information was administered to capture age, previous experience (both military and non-military), education level, English as first language, and gender.

RESULTS

Descriptive Statistics

The data of 84 participants were collected. All demographic data were absent for one respondent. Data were analyzed using pairwise deletion. Previous GPA was missing for six respondents. At least one graded performance score was missing for eight respondents.

During the study, real-world logistical issues precluded the ability to use the same instructor for all classes. In fact, the operational tempo of the organization resulted in some classes having two or more different instructors throughout the three-week block of instruction. An ANOVA with Tukey's *posthoc* tests found significant differences between the performance scores across a wide range of tests and classes suggesting that the instructors had fundamental differences in their grading criteria. For the single written measure, the reported scores showed no significant correlation to the number of displays and no significant differences as reported by an ANOVA ($p > .05$). Additionally, due to the classified nature of the tests, the items on the tests were not available for reliability analysis nor was there any possibility to assess their validity. As a result, performance measurement data was not used in further analysis.

Preliminary Data Review

Preliminary assumption checks revealed that the scores of the overall survey and the combined survey were normally distributed, as assessed by the Shapiro-Wilk test. The subscale scores for ICL, GCL, and ECL indicated a moderate violation of the assumption of normality as measured by the Shapiro-Wilk's test. However, since MANOVAs are robust to moderate non-normality, the analysis was conducted despite these violations (Lix, Keselman, & Keselman, 1996).

There were two GCL univariate outliers in the data, as assessed by inspection of a boxplot, however, removing these outliers had no significant impact on the analysis and the outliers were included in the final analysis. There were no multivariate outliers, as assessed by Mahalanobis distance ($p > .001$). There were linear relationships, as assessed by scatterplot and there was homogeneity of variance-covariance matrices, as assessed by Box's M test ($p > .001$). There was homogeneity of variances, as assessed by Levene's Test of Homogeneity of Variance ($p > .05$).

Tests for multicollinearity found a high correlation between age and experience (r = .86, $p < .001$) as well as between age and education level ($r = .76$, $p < .001$). Based on these findings, experience and education level were removed from the analysis (Kalnins, 2018). No other variables indicated correlations above .80 (see Table 1). Additionally, low correlations between age and gender with the DVs, combined with no significant differences between the treatments reported in hierarchical regressions with age and gender for each DV, indicated no shared variability between the treatments and age or gender, therefore age and gender were removed from the final analysis as covariates. Lastly, only four of the 84 participants reported that English was not their first language indicating that the cell counts were grossly uneven. As a result, English as first language was removed from the final analysis.

Table 1

Correlations of DVs and demographic information

		M	*SD*	1	2	3	4	5	6	7	8	9	10	11
1	No. of displays	1.51	.503	–										
2	Age	22.24	6.09	-.03	–									
3	Gender	1.37	.49	.05	-.16	–								
4	Years Mil experience	2.01	3.54	.00	.86***	-.18	–							
5	Years Non-Mil experience	4.02	4.88	-.04	.90***	-.13	.79***	–						
6	Education level	1.52	.95	-.13	.76***	-.03	.55***	.73***	–					
7	Overall Survey	4.10	.97	-.29**	.22*	.26*	.11	.21	.24*	–				
8	ICL	7.51	1.57	-.36**	.23*	.14	.11	.20	.31**	.50***	–			
9	GCL	8.04	1.36	-.13	.13	-.07	.05	.18	.21	.09	.36***	–		
10	ECL	5.50	1.78	-.44***	.10	.22*	.00	.08	.07	.56***	.30**	-.16	–	
11	Combined Survey	6.79	1.06	-.51***	.20	.18	.06	.21	.25*	.63***	.70***	.42***	.78***	–

Note: *$p < .05$, **$p < .01$, ***$p < .001$; ICL = intrinsic cognitive load, GLC = germane cognitive load, ECL = extraneous cognitive load

MANOVA

A one-way MANOVA with the number of displays as the IV (one vs. two) was run to determine if the addition of a second display affected the cognitive load of the student during the learning event. The 5 CL measures (2 overall, 3 subscales) served as DVs. Participants were provided with either one or two computer displays on their desks.

The differences between the single versus dual displays on the combined dependent variables was statistically significant, $F(5, 78) = 5.83$, $p < .001$; Wilks' $\Lambda = .73$; partial $\eta^2 = .27$. Follow-up univariate ANOVAs showed that there was a statistically significant difference in overall CL scores from the overall survey between the participants with one display ($M = 4.39$, $SD = .78$) compared to two displays (M = 3.83, SD = 1.06), $F(1, 82) = 7.48$, $p = .008$; partial $\eta^2 = .08$ using a Bonferroni adjusted α level of .01 to correct for familywise error (see Table 2). There was also a statistically significant difference in overall CL scores from the combined survey between the participants with one display (M = 7.33, SD = .86) compared to two displays (M = 6.28, SD = .97), $F(1, 82) = 28.16$, $p < .001$; partial $\eta^2 = .26$. ICL subscale scores indicated a statistically significant difference between the participants with one display (M = 8.07, SD = 1.32), compared to two displays (M = 6.96, SD = 1.61), $F(1, 82) = 11.84$, $p = .001$; partial $\eta^2 = .13$. Additionally, there was a statistically significant difference in ECL subscale scores between the participants with one (M = 6.30, SD = 1.67), compared to two displays (M = 4.73, SD = 1.55), $F(1, 82) = 20.07$, $p < .001$; partial $\eta^2 = .20$. And finally, there was no statistically significant difference in GCL subscale scores between the participants with one display (M = 8.22, SD = 1.21), compared to two displays (M = 7.88, SD = 1.48), $F(1, 82) = 1.37$, $p = .245$.

Table 2
Univariate Effects on Cognitive Load by Number of Displays

Dependent Variable	*df*	*df* error	*F*	No. of displays	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Overall Survey	1	82	7.48**	1	4.39	.15	4.10	4.68
				2	3.83	.14	3.55	4.12
Combined Survey	1	82	28.16**	1	7.34	.14	7.05	7.62
				2	6.28	.14	6.00	6.56
ICL	1	82	11.84***	1	8.07	.23	7.62	8.53
				2	6.96	.22	6.52	7.41
GCL	1	82	1.37	1	8.22	.21	7.80	8.65
				2	7.88	.21	7.46	8.29
ECL	1	82	20.07***	1	6.30	.25	5.80	6.80
				2	4.73	.24	4.24	5.22

Note: **p* < .05, ***p* < .01, ****p* <= .001; ICL = intrinsic cognitive load, GLC = germane cognitive load, ECL = extraneous cognitive load

DISCUSSION

The present study examined the use of computers with one vs. two displays in a military training field study in order to examine the impact of the number of displays on cognitive load. A number of worthwhile results were obtained. The findings of significantly lower reported overall CL support the current study's hypothesis that CL would be impacted by the addition of a second display. Specifically, the finding of lower reported ECL indicates that adding a second display reduces CL that is unnecessary to the learning event, thereby increasing capacity for ICL and GCL and facilitating a greater transfer of information from the working memory to long term memory. The finding of no significant differences between the two conditions of the IV in GCL is not surprising. In CLT, GCL is affected by instructional methods designed to facilitate learning and since both the treatment and the control group were exposed to the same curriculum, these findings further support Sweller's (1998) concept of GCL in CLT.

Additionally, results from the current study revealed significant differences in the perceived ICL between the group with a single display versus the group with two displays. According to CLT, ICL is based on the difficulty of the topic being learned. Thus, ICL should only be affected by the experience level of the student (Gerjets, Scheiter, & Cierniak, 2009; Klepsch, Schmitz, & Seufert, 2017; Paas, Tuoyinen, Tabbers, & Van Gerven, 2003; Sweller, Van Merriënboer, & Paas, 1998). Therefore, this finding in the current study is not consistent with the theory. The number of displays should have no effect on ICL.

One potential determinant of this finding could be instrument error introduced in the subscale survey items. The combined survey was adapted from a German study wherein the survey items were translated into English. This translation resulted in some items being worded in such a way that could have caused confusion in the participants' understanding of what was being asked, thereby introducing instrument error into the resulting scores. One example of the translation resulting in unusual wording in English is a GCL focused question that asked, "My point while dealing with the task was to understand everything correctly."

It is also possible that the questions, however they are worded, do not actually measure ICL, however, it is more likely that the German to English translation exacerbated or caused the re-emergence of a problem found in the early stages of the Klepsch et. al. (2017) study wherein the participants' understanding of the questions caused them to be unable to differentiate between ICL and GCL (Klepsch, et. al., 2017; Orru & Longo, 2019). There is some support for this possibility in the current study's finding of a low-moderate significant and positive correlation between ICL and GCL ($r = .36$, $p < .001$). The authors later added additional items designed to further delineate ICL from GCL resulting in the complete survey used in the current study. Future studies should further validate the Klepsch, et. al. (2017) instrument using variations of the items written in greater clarity for a wider audience of English-speaking participants.

Limitations

While the present study revealed noteworthy results, they must be interpreted in light of several limitations. Participants of the study were from a military initial job skills training program. Participants may not have been a representative sample of the general population of working adults for several possible reasons including the likelihood that certain personality characteristics are likely to influence the decision to join the military, the psychological characteristics required to complete basic military training, and participant age groups relative to the population. Also, approximately 23% of the participants were beyond their first 4-year term of enlistment. Thus, these participants are likely to possess characteristics that allow them to survive in a highly structured institutional environment for an extended period of time. Therefore, the phenomena examined in this study should be examined in other settings and other samples to determine the generalizability of the findings.

Most participants had recently completed basic military training. When asked to participate in the study, only four out of 89 students declined to participate despite multiple verbal and written assurances that their participation was voluntary and confidential. In the military environment in which this study was conducted, there are a number of factors, such as peer pressure, participant desire to showcase organizational citizenship behavior, or previously trained response to comply with requests from higher ranking persons, that may have contributed to the high participation rate among those approached. These factors may have influenced participation rates despite the fact that they were briefed that their participation would be confidential and voluntary. The high rate of participation could imply underlying psychological constructs of compliance and passivity held over from the intensive psychological training received in basic military training and may have affected the results of the study.

Another limitation was that the conditions of the study were in a field environment thereby reducing control of extraneous variables. Operational and logistical issues prevented the use of a single instructor for every group of participants. Variable instructor techniques, experience, and personalities may have impacted the results. One example of how this limitation affected the study was the statistically significant differences in performance ratings across classes causing the data to be unreliable, and therefore unusable as a dependent variable. Additionally, it was not possible to control the rate of instruction, number and length of breaks, or ambient noise of the classrooms. The tasks presented to the participants were complex, technical, mechanical tasks that could require high spatial intelligence. Also, there was no ability to leverage the material to measure the specific types of CL.

Theoretical Implications and Future Research

Despite these limitations, the current study provides partial support to the triarchic model of CLT and the possibility that ECL can be measured independently. It is logical to assume that reducing the need to switch between multiple windows on a computer display would correspondingly reduce unnecessary CL (i.e. extraneous). Therefore, the finding that ECL was significantly reduced by adding a second display to a complex task situation is not surprising. The second display likely allowed participants to display information more persistently and facilitated faster cross-referencing between multiple sources and therefore allowed for more cognitive capacity to be allocated toward the learning task.

The results of the present study also revealed moderate support for the reliability and validity of the Klepsch, et. al. (2017) instrument for measuring the subcomponents of CL. In regards to reliability, beyond the overall Cronbach's alpha of .64, the survey also presented moderate Cronbach's alphas in each type of CL (ICL $\alpha = .71$; GCL $\alpha = .71$; ECL $\alpha = .69$). These findings are similar to those found by Eitel, Bender, and Renkl (2019) on ICL ($\alpha = .77$) and ECL ($\alpha = .71$; p. 24). In relation to validity, a correlation analysis between the traditional CL measures and the new instrument revealed a significant moderate correlation

($r = .63$, $p < .001$). Additionally, the findings support the logical conclusion that adding a second screen will reduce the amount of material that must be kept in the working memory and therefore reduce CL. Together, these findings suggest that the Klepsch, et. al. CL instrument merits further study.

There are a number of future research areas that can further elucidate the nature of CL and its components, as well as provide a better understanding of measuring these constructs. First, research wherein the tasks presented to participants are designed to elicit each type of CL would further validate the Klepsch, et. al. (2017) survey when combined with single or dual display computers. For example, task components designed to create additional ECL involving multiple windows on a single display compared to tasks designed with reduced ECL involving multiple windows on dual displays could create a larger effect, allowing researchers to compare the effect sizes of the results and further refine and validate the ECL subscale of the instrument. This focus of future research may also provide insight into the differences in ICL found in the current study.

Another valuable area for future research would be to conduct a study of the types of CL as it relates to single or dual displays in a within-persons design. Developing tasks designed to generate varying levels of CL and its subcomponents, and then examining how individuals respond to each of the tasks differently would provide further insight into how the types of CL interact with the number of displays while controlling for differences in participant characteristics. Conducting these studies in lab environments would also allow for more robust control of extraneous variables such as ambient noise and instructor characteristics.

Another focus for future research should be toward understanding the point at which the additional display space provided by multiple displays reaches diminishing returns regarding the reduction of ECL during the learning event. Further, researchers should determine if using one large display capable of displaying multiple documents at once produces similar reductions in ECL to those found in the current study.

In the current study, participants were limited to having access only to information and applications pertinent to the task. There was no method for determining how, or even if, participants utilized the second display. The closed network in the current study allowed for better control over possible distractions such as chat or email, however, future studies should explore how employees use a second display to determine how CLT interacts with other pertinent theories (e.g., Task Switching Theory, Multi-tasking Theory, etc.).

Finally, the findings of the current study suggest that the use of two displays in research on learning can help researchers refine our understanding of the learning process. Reducing ECL by providing research participants with two displays can provide future research participants with more bandwidth for GCL and allow researchers to better understand what types of GCL inducing tasks can enhance the transfer of information into long-term memory.

Practical Implications and Future Directions

In addition to the theoretical contributions of the present study, a number of practical implications are indicated by the results. The results demonstrated that having two displays on one’s desk reduces unnecessary mental processing during a single task learning event by up to 20%, leaving more cognitive bandwidth available for learning. These findings have important implications for organizations. Specifically, the reduction in cognitive bandwidth afforded by the use of two displays facilitates greater concentration, productivity, and learning and may justify supplementary equipment costs for businesses and schools.

The present study's findings suggest that curriculum development professionals would benefit from developing curriculum with dual displays in mind. Combining Lanir, et. al.'s (2013) finding that information persistence leads to higher retention with the current study's demonstration of the efficacy of dual displays on desktop computer systems creates an opportunity for curriculum developers to maximize GCL through information presentation on both displays. These concepts could be combined if learners could see interconnecting information about a complex topic on both displays and are able to switch the information on each display between other pieces of interconnecting data to form a more complete understanding of how small connections contribute to the bigger picture. As a specific example, the learner could be presented with an overall diagram of the cardiovascular or other physiological system in the human body on one display and the second display could present information about each component of the system and how it contributes to the overall system. Learners could also interact with the first display (e.g. switching it to a presentation of the nervous system) to show how each component interacts with other physiological systems. Together, learners would have a better overall presentation of the information while reducing the unnecessary cognitive bandwidth associated with finding the information in multiple other sources.

Advances in technology often cause a distraction in the learning environment. As this study has shown, technology can also be used to reduce those distractions and enhance learning. With further research, we should be able to learn more about the nature of the interaction between CL and technology and advance the science of how we learn.

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IRB APPROVAL LETTER

ANGELO STATE UNIVERSITY
College of Graduate Studies
Institutional Review Board

1/22/2018

Dr. Cheryl Stenmark
Dept. of Psychology, & Sociology
Angelo State University
San Angelo, TX 76909

Dear Cheryl:

The addendum submitted by your student, Robert Miller, for his previously approved project titled, "*The Effect of Dual Display Personal Computers on Learning: A Cognitive Load Study*" has been reviewed and APPROVED in accordance with federal regulations 45 CFR 46.

The approved addendum is effective beginning January 22, 2018. Please be aware that the protocol will expire one year from its original approval date, which will be January 22, 2019. If the study will continue beyond that date, you must submit a request for continuation before the current protocol expires.

The approved addendum is for protocol #STE-012218. Please include this number in the subject line of in all future communications with the IRB regarding the protocol.

Sincerely,

Teresa Hack, Ph.D.
Chair, Institutional Review Board

Dr. Teresa Hack, IRB Chair | ASU Station #11025 | San Angelo, Texas 76909
Phone: (325) 486-6121 | Fax: (325) 942-2194

BIOGRAPHY

Robert Allen Miller received his B.S. in Interdisciplinary Studies from Park University, Parkville, Missouri, in 2017.